ıdian J. Phys. 71A (3), 335-341 (1997)

IJP A
— an international journal

PROTON IRRADIATION ON TEXTURED BISMUTH BASED CUPRATE SUPERCONDUCTORS

Pintu Sen[a], S.K. Bandyopadhyay[a], P.Barat[a],
P. Mukherjee[a], A.K. Ghosh[b] & A.N. Basu[b]
Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar,
Calcutta 7000 64.[a]
CMPRC, Department of Physics, Jadavpur University,
Calcutta 7000 32.[b]

Abstract: Textured bulk polycrystalline samples of Bismuth based cuprate superconductors have been subjected to irradiation with 15MeV protons. In case of Bi-2212, there has been substantial increase in Tc, which may be due to proton induced knock-out of loosely bound oxygen. In case of (Bi,Pb)-2223, there has been a reduction in Tc. The difference in behaviour in these two systems towards proton irradiation has been explained.

Keywords: Texturing, Proton Irradiation, Bi-based Superconductors

PACS nos. 61.80J, 76.10.

1. Introduction

High temperature superconductors are highly anisotropic in their physical properties like resistivity, critical current density (Jc), upper critical field etc.. Grain orientation along a certain direction (i.e texturing) helps achieving better conductivity, Jc etc.. Moreover, the superconductivity of cuprate systems strongly depends on oxygen content. The oxygen in excess of the stoichiometry acts as a source of holes in these p-type superconductors [1]. The change in oxygen content has large effects on Tc, resistivity rtc. We had earlier observed an increase in Tc in polycrystalline Bi-2212 system by α-irradiation and the increase in Tc was presumed to be due to knock-out of oxygen caused by α-particles' [2]. In addition, charged particle irradiation creates large number of point defects which act as strong pinning centre for high critical current density [3].

In this paper, we report irradiation studies with 15MeV proton on bulk polycrystalline $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) and $Bi_{1.81}Pb_{0.34}Sr_{1.91}Ca_{2.03}Cu_{3.06}O_{10+\delta}$ (Bi(Pb)-2223). We have employed textured samples to obtain more conclusive and better results than random bulk samples.

2. Experimental

Bi-2212 Samples were prepared from nitrates of Bi, Sr, Ca, Cu with nominal composition by usual solid state reaction. The detailed synthesis is reported elsewhere [4]. The microstrucures of the sample with highest degree of texturing were examined by Hitachi S 415 Scanning Electron Microscope with accelerating voltage of 25 Kv (fig.1a & Fig. 1b).

1a

1b

Fig.1a : Scanning Electron micrograph (x 2500) of an annealed Bi-2212 sample prepared at 600 MPa. Fig.1b : Scanning Electron micrograph (x 2500) of an annealed Bi(Pb)-2223 sample prepared at 400 MPa.

The resistivities of rectangular-bar-shaped samples, mounted on Leybold 10-300 Cryogenerator, were measured by four-probe method. The current through the samples was kept at 1mA. Irradiation was done with a beam of 15 Mev proton obtained from the Variable Energy Cyclotron in Calcutta. The range of 15 Mev proton is 750 microns which ensured uniform damage throughout bulk of sample having thickness typically around,500 microns. The beam current was 250 nA. Electrical insulation of the target holder from the beam tube was ensured by perspex flange and teflon bush in the screws connecting the target holder and beam line. The samples attached to the aluminium target holder were cooled by a flow of pressurized water (pressure 40 p.s.i). The number of protons deposited was obtained by measuring the charge collected on the target holder through a current digitizer and a scalar. The dose received by the samples were 1×10^{14}, 1×10^{15} and 2×10^{15} proton/cm^2. The oxygen contents of the irradiated and the unirradiated samples were determined by iodometric titration.

3. Results and discussions

Figures 2 and 3 describe the plots of resistivities versus temperature for various doses of proton irradiated Bi-2212 and (Bi,Pb)-2223 respectively.From the figures and table 1, we observe that Tc(R=0) of Bi-2212 has increased monotonically from 69K to 79K with increasing doses, whereas in Bi(Pb)-2223, there has been a decrease from 104K to 77K with increasing doses.Again, Tc(onset) of Bi-2212 has increased from 74K to 94K with increasing doses but in Bi(Pb)-2223, it remains almost constant at 115K except at the highest dose (77K) as shown in Table 1. This can be explained as follows. The structural stability

Table-1. Resistivities and Tc's of Bi-cuprates at different doses

Sample	Dose (p/cm^2)	Resistivity (300 K)	Tc(R=0) (K)	Tc(onset) (K)
Bi-2212	Unirradiated	5.2	69	74
	$1x10^{14}$	11.4	69	75
	$1x10^{15}$	14.3	74	85
	$2x10^{15}$	17.5	79	94
Bi-2223	Unirradiated	5.8	104	115
	$1x10^{14}$	7.3	104	115
	$1x10^{15}$	15.2	103	115
	$2x10^{15}$	127.5	77	104

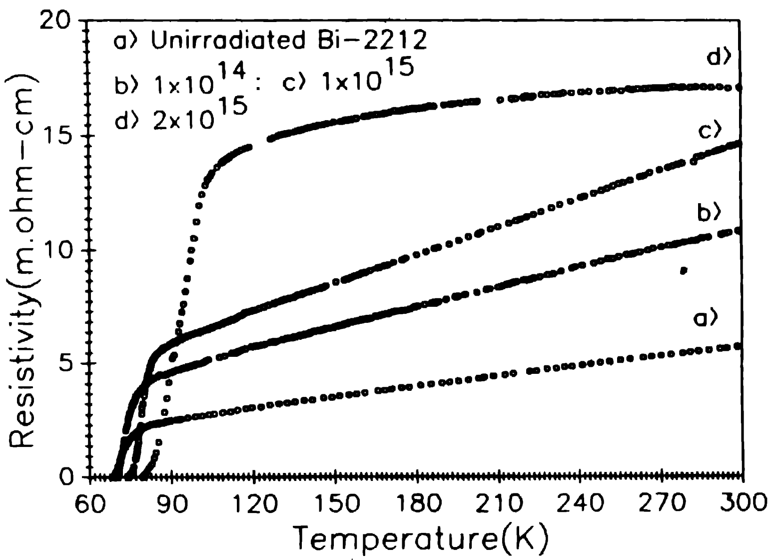

Fig 2 Variation of resistivity of Bi2212 as a function of doses and temperature

in these cuprates is governed by a tolerance factor **t** [5] which is defined as:

$$t = (R_{Bi-O}) / (1.4 R_{Cu-O})$$

where R_{Bi-O} and R_{Cu-O} are the bond lengths of Bi-O in the rock-salt block and Cu-O in the perovskite block, respectively.

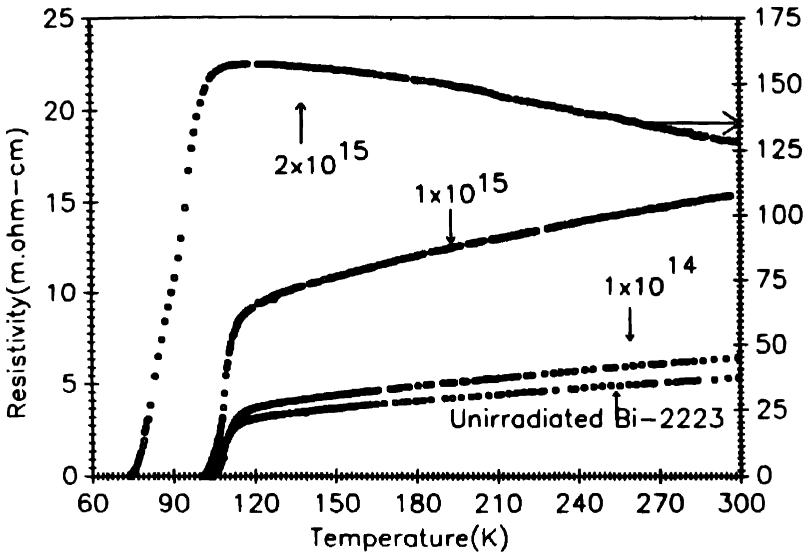

Fig.3 Variation of resistyvity of Bi-2223 as a function of doses and temperature

In undoped Bi-2212, t turns out to be 0.78 which is less than the value needed for structural stability ($0.8 < t < 0.9$). Since Cu-O bond is rigid, the structural stability is attained by accommodating excess oxygen in Bi-O layer, whereby Bi-O bond distance increases to 0.26 nm and the tolerance factor t comes within the proper range. The original unirradiated Bi-2212 sample is in the overdoped region with respect to excess oxygen content ($\delta = 0.20$) [6]. The excess oxygen is loosely bound and is vulnerable to be knocked out by particle irradiation. As a result, Tc(R=0) and the intragrain Tc i.e Tc(onset) increase monotonically with doses till it is in the overdoped region. On the other hand, in Pb doped Bi-2223, due to partial substitution of Bi^{+3} (0.93 A^0) by Pb^{+2} (1.20 A^0) with a larger ionic radius, tolerance factor t comes to lie in the range of stability. Hence Bi(Pb)-2223 dose not much absorb excess oxygen (δ =. 0.14). Hence Tc(onset) and Tc(R=0)of Pb doped material remains unchanged up to dose 1 x 10^{15}proton/cm^2. There were similar observations by us in case of α-irradiated (Bi,Pb)-2223 [7].

In the case of highest dose(2 x 10^{15} proton/cm^2), Tc(onset) and Tc(R=0) decreased to 105K and 77K respectively. The decrease is due to the generation of large number of defects which cause destruction of weak-linking between the grains and brodening of transition width (ΔTc=28K). This destruction of weak-linking is also observed for other doses in both Bi-2212 and Bi(Pb)-2223 systems where resistivity increases. with dose. The defects are generated primarily due to radiation induced displacement of atoms and can be quantified through displacement per atom or, d.p.a., which for a particular irradiation is proportional to dose. With the help of Monte Carlo simulation program TRIM-95 (TRansport of ions in matter), we have estimated d.p.a.s of 15MeV protons in Bi-2212 and (Bi,Pb)-2223 for a dose of $1x10^{15}/cm^2$. These are around $1.26x10^{-5}$, which is an order less than α. With low d.p.a., proton creates cascades of point defects, which are effective for generation of large number of pinning centres, rather than clusters of localised defects created by α with larger d.p.a.. Thus, protons might be more effective than α for enhancement of Jc. We are carrying out studies of Jc of proton irradiated (Bi,Pb)-2223 as well as Bi-2212.

4. Conclusion

We have irradiated textured polycrystalline samples of Bi-2212 and (Bi,Pb)-2223 with 15MeV protons. There is an increase in Tc in case of Bi-2212, whereas the decrease is there for (Bi,Pb)-2223. The difference in behaviour of these two systems with respect to proton irradiation bears close analogy to that in α-irradiation. The difference with α is in d.p.a.. protons with lower d.p.a. may be more effective than α for enhancement of Jc.

Acknowledgements

The authors would like to thank Dr. Bikash Sinha and Dr. J. N De for their constant encouragement. The authors are grateful to the Humboldt Foundation, Germany, for Laybold 10-300 Cryogenator.

References

[1] J.D.Jorgensen, Physics Today **44** (1991) 34; and references therein.

[2] S.K.Bandyopadhyay, P.Barat, S.K.Kar, Udayan De, A.Poddar, P.Mandal, B.Ghosh and C.K.Majumdar, Solid State Commun. **82** (1992) 397.

[3] B.Raveau, Physics Today **45** (1992) 53.

[4] Pintu sen, S.K.Bandyopadhyay, P.Barat, P.Mukherjee, P.k.Mukhopadhyay and A.De, Physica **C255** (1995) 306.

[5] H.Zhang and H.Sato, Physica **C214** (1993) 265.

[6] C.Allgeier and J.S.Schilling, Physica **C168** (1990) 499.

[7] S.K.Bandyopadhyay, P.Barat, Pintu Sen, Udayan De, A.De, P.K.Mukhopadhyay, S.K.Kar and C.K.Majumdar, Physica **C228** (1994) 109.